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Rainfall Induced Infiltration Into Sewer Systems

Report To Congress

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NOTICE

TABLE OF CONTENTS

CHAPTER 2

PROBLEM ASSESSMENT

This chapter discusses the characteristics of and problems associated with rainfall induced infiltration (RII) into sanitary sewer systems. Included are a definition of RII; a discussion of the typical problems associated with RII; a description of possible pathways by which rain can be rapidly transported from the ground surface to where it enters a sanitary sewer system; a discussion of the types of defects and connections through which RII may enter a sewer system; an assessment of the key factors which may be important for explaining the potential for RII occurrence in specific sewer systems; and a summary of RII case studies.

BACKGROUND

The entry of extraneous water into sanitary sewer systems has been recognized for many years as a significant problem in communities throughout the country. This extraneous water, termed infiltration and inflow (I/I), consists of groundwater and storm water which enter the sewer system through defects in pipes and manholes and through direct connections to the sewer system. When present in excessive amounts, I/I can cause wastewater overflows and bypasses from manholes and pump stations, bypassing and/or inadequate processing of wastewater at treatment plants, and flooding of building basements with wastewater.

The need to address excessive I/I was dictated in the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500). Under this law, Congress mandated that all "excessive" I/I be removed from a sanitary sewer system before a construction grant for wastewater treatment facility improvements could be awarded. EPA has interpreted "Excessive" I/I as that portion of the total I/I which could be cost-effectively removed, i.e., the cost for removal would be less than the cost for transport and treatment of the "excessive" I/I flows.

In the years immediately following the enactment of the 1972 law, the EPA developed guidelines for conducting I/I cost-effectiveness analyses and sewer system evaluation surveys (SSESs) to identify excessive I/I (Appendix B). EPA regulations at 40 CFR Part 35 define the terms "infiltration" and "inflow" as follows:

> **Infiltration.** Water other than wastewater that enters a sewer system (including sewer service connections and foundation drains) from the ground through such means as defective pipes, pipe joints, connections, or manholes. Infiltration does not include, and is distinguished from, inflow.

> **Inflow.** Water other than wastewater that enters a sewer system (including sewer service connections) from such sources as, but not limited to, roof leaders, cellar drains, yard drains, area drains, drains from springs and swampy areas, manhole covers, cross connections between storm sewers and sanitary sewers, catch basins, cooling towers, storm waters, surface runoff, street wash waters, or drainage. Inflow does not include, and is distinguished from, infiltration.

In general, the understanding of infiltration was that it entered the sewer system <u>indirectly</u> via groundwater seepage into underground sewer defects, whereas inflow was rainfall runoff entering through <u>direct</u> connections. An exception to this generalization was later made when directly connected foundation drains were reclassified as infiltration rather than inflow, thus recognizing the sustained flow contribution of foundation drains in areas of high groundwater.

The EPA guidelines described procedures for separating and quantifying infiltration and inflow by use of flow data. Specifically, infiltration was calculated as the difference between total flow and estimated wastewater input on non-rainfall days. Inflow was calculated as the difference between the total flow during a large storm event and the total flow on the nearest non-rainfall day. Thus, in practice, the term "inflow" came to be synonymous with short-term, rain-induced I/I. The EPA guidelines acknowledged that both infiltration and inflow are affected by rainfall, but that it was not possible to precisely quantify infiltration and inflow in accordance with their literal definitions. As a result, it was concluded that the accuracy levels of the calculated values were adequate for estimating that portion of the I/I which might be considered excessive.

Subsequently, communities throughout the country conducted I/I analyses and SSESs using the EPA guidelines, and many undertook sewer system rehabilitation programs to remove the I/I that had been categorized as excessive. While I/I flows were reduced in a number of such systems, in others, the anticipated flow decreases did not occur. One possible explanation of why these programs failed is that infiltration may have been incorrectly identified as inflow. This can happen when water infiltrates into the sewer system through pipe and manhole defects, but produces a peak flow response similar to that of inflow from direct connections. Inflow connections can typically be eliminated at a lower cost (per unit of flow removed) than can defects in pipes and manholes. Therefore, if flows due to infiltration are incorrectly identified as being due to inflow, an invalid or substantially overestimated assessment of the cost effectiveness of I/I correction may result.

Problem Assessment

One wastewater system with extremely high rain induced extraneous flows is the East Bay Municipal Utility District (EBMUD) in California, which includes the City of Oakland and six adjacent communities. During large rainfall events, the EBMUD system can experience flows as high as twenty (20) times the average dry weather flow. As a result, peak flows exceed the conveyance capacity of the sewer system, causing overflows onto city streets and bypasses of untreated wastewater to San Francisco Bay.

To address these problems, EBMUD and its tributary communities undertook extensive studies to identify and quantify the rainfall induced extraneous flows in their sewer system. The goal of these studies was to develop a regional plan to eliminate peak flows that could cost-effectively be reduced, and then to adequately process the remaining volume of wet weather wastewater.

The comprehensive I/I study conducted by the EBMUD communities concluded that only a small fraction of the high peak flows occurring during rainfall events could be attributed to direct inflow. The majority of the rainfall induced flow was attributed to infiltration, and was called "rainfall dependent infiltration" in the EBMUD studies. Thus, EBMUD became the impetus for the study on rainfall induced infiltration called for under the 1987 Water Quality Act.

DEFINITION OF RII

For the purpose of this report, we have defined rainfall induced infiltration (RII) as follows:

> **Rainfall Induced Infiltration.** RII is a particular form of infiltration which behaves like and is sometimes confused with storm water inflow. RII generally occurs during and immediately after rainfall events and it is believed to be caused by the seepage of percolating rainwater into defective pipes (in many cases service connections or laterals) which lie near the ground surface. These circumstances cause a large portion of the rainfall to enter the system relatively quickly and the extraneous flow lasts only a short time after the rainfall episode is over. The combination of these factors causes RII to be of relatively short duration and high intensity as compared with typical infiltration which is generally constant in intensity and of longer duration.

Rainfall induced infiltration can be distinguished from "classical" infiltration because it results in a peak flow response in sanitary sewer systems which may be indistinguishable from that of direct storm water inflow. For the purposes of the discussion in this report, the long-term, sustained classical type of infiltration will be described by the term "groundwater infiltration" (GWI). "Storm water inflow" (SWI) will be used as the term for direct inflow as defined by EPA. Both GWI and RII are forms of infiltration, as described by the EPA definition, but differ primarily in their flow response.

The distinctions between SWI, GWI, and RII are illustrated by the hydrographs in Figure 2-1. As shown in the figure, SWI produces a rapid, peak flow response to rainfall which recedes quickly after the rainfall stops. Rainfall may also produce a net increase in the sustained GWI flow rate, as shown in the figure. RII response may be as rapid as that of SWI, or may include a delayed response which lags the peak rainfall intensity by several hours and then recedes slowly. In most sewer systems, the RII response is likely a continuum from a rapid peak flow to a more gradual, prolonged response similar to GWI. Therefore, the separation between the RII and GWI portions of the hydrograph may not be well-defined. RII becomes most significant when the type of flow response is more like inflow, i.e., it results in a rapid and high peak flow in the sanitary sewer system.

PROBLEMS ASSOCIATED WITH RII

The problems associated with RII are those due to the high peak flows which occur during and immediately following rainfall. Typical RII problems include wastewater overflows and bypasses from manholes and pump stations in the sewer system, and flooding of building basements. Wastewater backing up into homes or overflowing into city streets is a hazard to public health and, in most cases, is a clear violation of the discharge requirements of the sewerage agency. Additionally, wastewater bypassed to drainage channels may result in water quality degradation in downstream surface waters. If the flows reaching the wastewater treatment plant are much higher than the plant's capacity, deliberate bypassing may be necessary to avoid hydraulically overloading the plant. At very high plant flows, inadequate wastewater treatment and inability to meet discharge requirements may result. In all cases, excessive RII flows result in increased operation and maintenance costs for transport and treatment.

An ancillary problem associated with RII is that there is the potential for exfiltration of untreated sewage at these same pipe and manhole defects. This problem is especially likely to manifest itself when the sewer pipe is above the water table. In some cases, discharged sewage may cause ground-water contamination; in other cases it might be channelled by sewer trenches to potential points of direct human exposure.

The peak nature of flows due to RII, and the magnitude of these flows in some systems, means that wastewater collection, transport, and treatment facilities must be designed for capacities that greatly exceed normal peak dry weather flows. Thus, very large capital expenditures may be required to construct facilities that

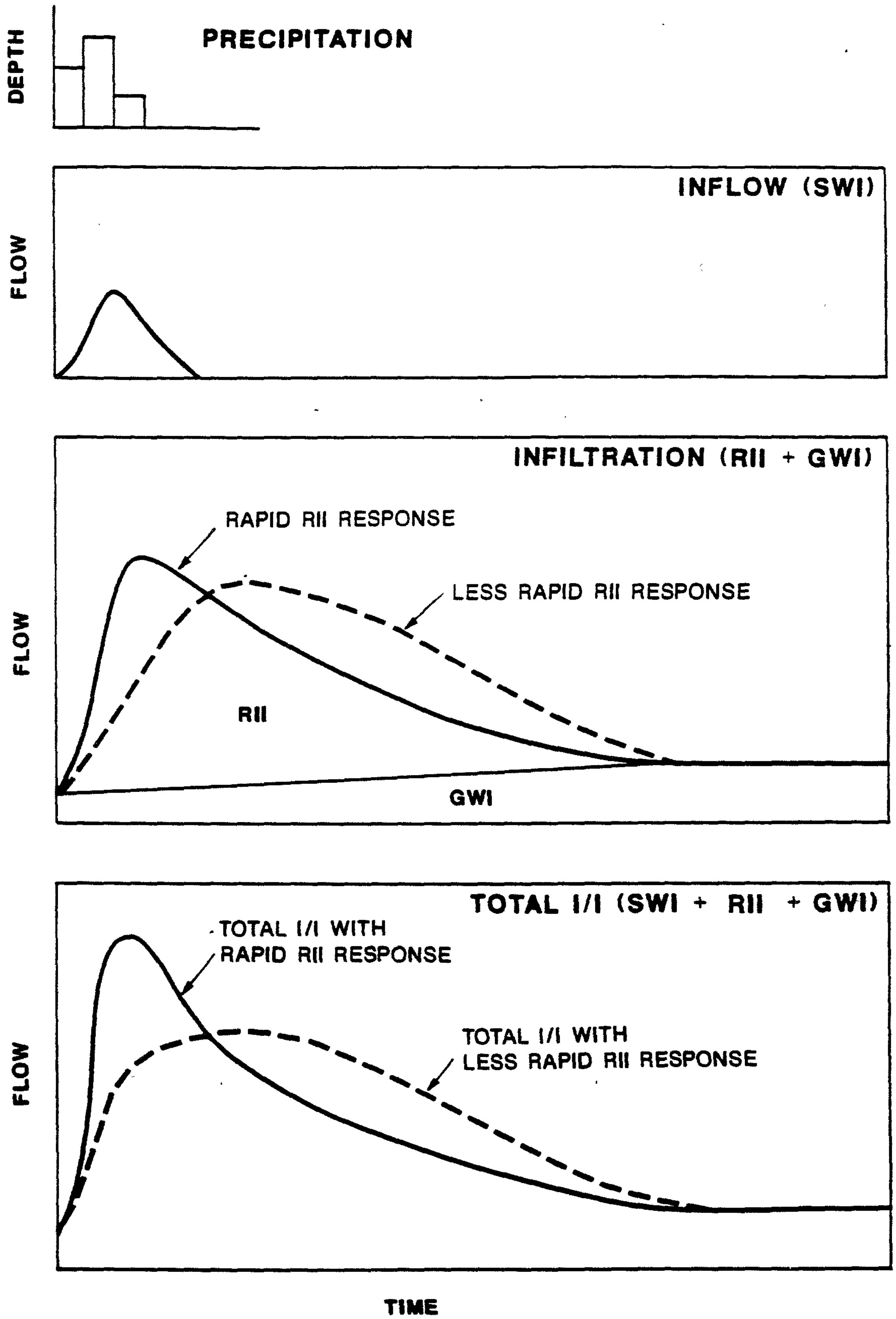

FIGURE 2-1

TYPICAL EXTRANEOUS FLOW HYDROGRAPHS

can handle the RII flows. Funding for such construction may be difficult, if not impossible, to obtain. Similarly, system capacity that might otherwise be available for future growth must be used for RII. In systems with severe capacity limitations and problems due to RII, building moratoriums may be necessary to restrict further increases in wastewater flows.

The alternative to providing excess system capacity to handle high RII flows is to reduce RII through sewer system rehabilitation. However, as will be discussed in more detail later in this report, achieving substantial RII flow reductions through rehabilitation can be very difficult and costly. Part of this problem is due to the fact that in many areas, a significant portion of RII may originate on private property (from building laterals and foundation drains). Many communities have invested considerable sums of money (both under local programs and with state and federal funding) in rehabilitation programs that have proven ineffective in reducing I/I flows. The failure of many of these programs has been due in part to the failure to properly identify RII as the major component of I/I, and to implement an adequate program for RII control.

As noted previously, RII has been identified as the primary cause of wet weather problems in the EBMUD wastewater system. During large storms, overflows occurred at over 175 locations within the community collection systems and about ten times each year from one or more of seven shoreline bypass points on the District's major interceptor sewer along San Francisco Bay. To eliminate these problems and comply with discharge requirements, EBMUD and its tributary communities have had to initiate a major program of sewer system rehabilitation and construction of facilities to handle wet weather flows, at a cost of over $600 million. The section on Case Studies presented later in this chapter describe the problems associated with RII in nine other sewer systems throughout the country.

POSSIBLE RII PATHWAYS AND FLOW RESPONSE

Storm water may reach sewer system openings through different pathways from the ground surface. The resulting RII flow response will vary depending upon the type and length of the pathway that the water follows. Factors such as the characteristics of the soils, geology, groundwater, topography, and trench backfill materials will influence the speed of the flow response. A very rapid response would be expected in situations in which the RII pathway is more like a direct channel to the sewer entry point. A slower response would be expected in cases where the permeable backfill material in the sewer trench acts as a drain for the water in the surrounding soil.

Problem Assessment

- The RII flow response may be indistinguishable from that of direct storm water inflow (SWI) if it is very rapid and short-termed.
- The RII flow response is likely a continuum from a very gradually changing flow, similar to GWI, to a rapid peak, similar to SWI.
- The traditional methodology for analysis of I/I has resulted in RII being incorrectly identified as inflow in many sewer systems.
- Peak wet weather flows due to RII can cause overflows and bypasses in sanitary sewer systems and at wastewater treatment plants, as well as backups of wastewater into building basements. Peak wet weather flows include base wastewater flow plus GWI plus rain induced infiltration and inflow.
- To handle RII flows, sewer pipelines and pump stations and wastewater treatment plants must be designed with considerable additional capacity to convey and treat relatively infrequent, but large peak flows.
- Estimated RII ranged from over 50 to nearly 100 percent of total peak rain induced extraneous flow for the ten case studies documented in this investigation. Rain induced extraneous flow includes only rainfall infiltration and inflow.
- Possible pathways of storm water flow from the ground surface to the sanitary sewers may include:
  - Soil channels from the ground surface to sewer defects.
  - Exfiltration out of leaky storm drains through the soil to defects in sanitary sewer pipes.
  - Seepage through pavement cracks with horizontal movement along the street subbase to the upper portions of sanitary sewer system manholes.
  - Percolation into permeable trench backfill materials and along pipe trenches to defects in sewer pipes.
- RII was found to enter sanitary sewers through pipe defects in sewer mains and building laterals, manhole defects, and foundation drains directly connected to service laterals.

TABLE 2-1

SUMMARY OF CASE STUDIES

System Name	System Size* (miles)	Points of RII Entry	Probable Factors Affecting: Points of Entry	Probable Factors Affecting: Flow Response	PWWF/ADWF* Ratio	Control Efforts
EBMUD, CA	1,500	• Sewer main defects • Service lateral defects	• Age, condition of sewers. • High density • Poor maintenance • Ground movement	• Shallow mains and laterals • Clay soils • Steep slopes	20	"Comprehensive" rehabilitation (mains plus entire laterals) in about 50 percent of service area; primarily replacement and slip-lining.
Springfield, OR	165	• Sewer main defects • Service lateral defects	• Condition of sewers	• High groundwater	11	"Complete basin" rehabilitation (mains plus lower laterals) in four basins; primarily replacement and grouting.
MMSD, WI	2,200	• Foundation drain connections • Manhole frame/ chimney defects • Sewer main defects • Service lateral defects	• Foundation drain connections • Frost heave	• Common trench laterals • High groundwater	7.5	Manhole rehabilitation. Foundation drain disconnection in two communities only.
NEORSD, OH	1,200	• Sewer main defects • Service lateral defects • Common trench manhole dividers (walls, plates)	• Condition of sewers	• Common trench storm/ sanitary sewer construction	12-20+	Common trench sewer separation and manhole rehabilitation. Vortex regulators to restrict storm drain flow.
Baton Rouge, LA	1,500	• Sewer main defects • Service lateral defects	• Age, condition of sewers • Poor maintenance	• Trenches in drainage ditches • Shallow laterals	3.5	Rehabilitation in four pilot areas, primarily slip-lining, grouting, and replacement of sewer main defects identified through smoke testing.

TABLE 2-1

SUMMARY OF CASE STUDIES (CONTINUED)

System Name	System Size[a] (miles)	Points of RII Entry	Probable Factors Affecting: Points of Entry	Probable Factors Affecting: Flow Response	PWWF/ADWF[b] Ratio	Control Efforts
Springfield, MO	500	• Sewer main defects • Service lateral defects • Foundation drain connections	• Age, condition of sewers	• Shallow bedrock (limestone) • Perched groundwater	8	Long-term, routine inspection and rehabilitation of mains on priority basis.
N&S Shenango, PA	90	• Pipe joints	• Defective pipe joints	• Trenches in drainage ditches • High groundwater	7	Slip-lining of sewer mains and lower laterals.
Ames, IA	135	• Foundation drain connections	• Foundation drain connections	• High groundwater	6	Foundation drain disconnection program.
Coos Bay, OR	80	• Sewer main defects • Service lateral defects	• Condition of sewers • Ground settlement	• Shallow laterals • High groundwater	8	Limited sewer main rehabilitation.
Tulsa, OK	1,400	• Sewer main defects • Service lateral defects • Manhole defects	• Condition of sewers	• Shallow laterals • Shallow bedrock (limestone) • Granular trench backfill	3.5	Rehabilitation in selected subbasins; primarily lining, replacement, and spot repairs of defects identified through field work.

a Separated portion only, if partially combined system.
b PWWF = Peak Wet Weather Flow; ADWF = Average Dry Weather FlowPWWF may include varying amounts of SWI and GWI, and is typically based on a specified design storm for each system. Therefore, PWWF/ADWF ratios are not necessarily comparable between systems.